LECTURE - DEMONSTRATIONS

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1 Machina Reproducatrix
DR. A. J. ANGYAN, Physiological Institute, Budapest.

A description of the demonstration is given on page 933.

2 The growth of concepts and their physical analogues.
MR. G. PASK, System Research Ltd., London

This demonstration is described in the Appendix to Mr. Pask's paper, Session 4B, Paper 7.

3 Conditional Probability Computer
DR. A. M. ANDREW, NPL.

A description of the demonstration is given on page 945. Further details of the Conditional Probability Computer are given in the papers by Dr. A. M. Uttley, Session 1, Paper 5 and by Dr. A. M. Andrew, Session 3, Paper 5.

4 A Simple Computer for Demonstrating Behaviour.
DR. W. ROSS ASHBY, Barnwood House Hospital, Gloucester.

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PROF. D. B. FRY and MR. P. DENES, University College, London

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8 DEUCE: Experiments relating to visual perception and simple self-modifying programmes
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11 The Grouped Symbol Associator (an aid to Medical Diagnosis)

DR. F. A. NASH, Western Hospital, London

This exhibit is fully described in the Lancet, April 24th, 1954, pp. 874-5. See also Dr. Nash's contribution to the paper by Dr. Paycha, Session 4B, Paper 4.

MACHINA REPRODUCATRIX

AN ANALOGUE MODEL TO DEMONSTRATE SOME ASPECTS OF NEURAL ADAPTATION

by

DR. A. J. ANGYAN

MEMORY has always presented an important problem to physiologists and neurologists, and there have been many attempts to interpret the brain and its memory function by physical analogues or illustrations. The early ones included Dubois Reymond, Pavlov (*ref. 16*) who used telephone analogues for both unconditioned and conditioned reflexes, and the Hungarian neurologist, Jendrassik (1912) who used analogies of physical induction and resonance. More recent theories of conditioned reflexes Young (1938, *ref. 22*), Hilgard and Marquis (1941, *ref. 9*), Konorski (1948, *ref. 11*), and Hebb (1949, *ref. 8*) used similar ideas in attempting to make hypotheses on plastic adaptation using various electronic circuits. All-or-nothing features of synapses were detected by microelectrode studies and discussed by McCulloch and Pitts (1943, *ref. 13*), and by Eccles (1953, *ref. 6*). Cragg and Temperley (1954, *ref. 5*) used electromagnetic phenomena, i.e. field processes.

However it is clear that all these analogies are only very tentative ones, even if they do show some features of the brain. They are useful in helping to explain the meaning of biological terms, and, not less important, they may help to clear up errors and inconsistencies in our terms, and of the physical analogues associated with them. Physiologists are obliged to define clearly the concept of memory as a mechanism of a highly organized complex living system.

Machina Reproducatrix, which is shown here (photo, *fig. 1*) is a model which attempts to demonstrate some, but not all, of the recently formulated concepts of nervous adaptation. It is based on Dr. Grey Walter's Machina Speculatrix and its development Machina Docilis. It is a relatively simple analogue model of a simplified pattern of the innate and acquired reflex connections of a living being. It is a simple model compared with the more refined concepts of Dr. McCulloch (*ref. 14*) or Dr. Rosenblatt's perceptron, Dr. Uttley (*ref. 19*) and his Conditional Probability system or Dr. Ashby (*ref. 4*) and his habituation and homeostat models.

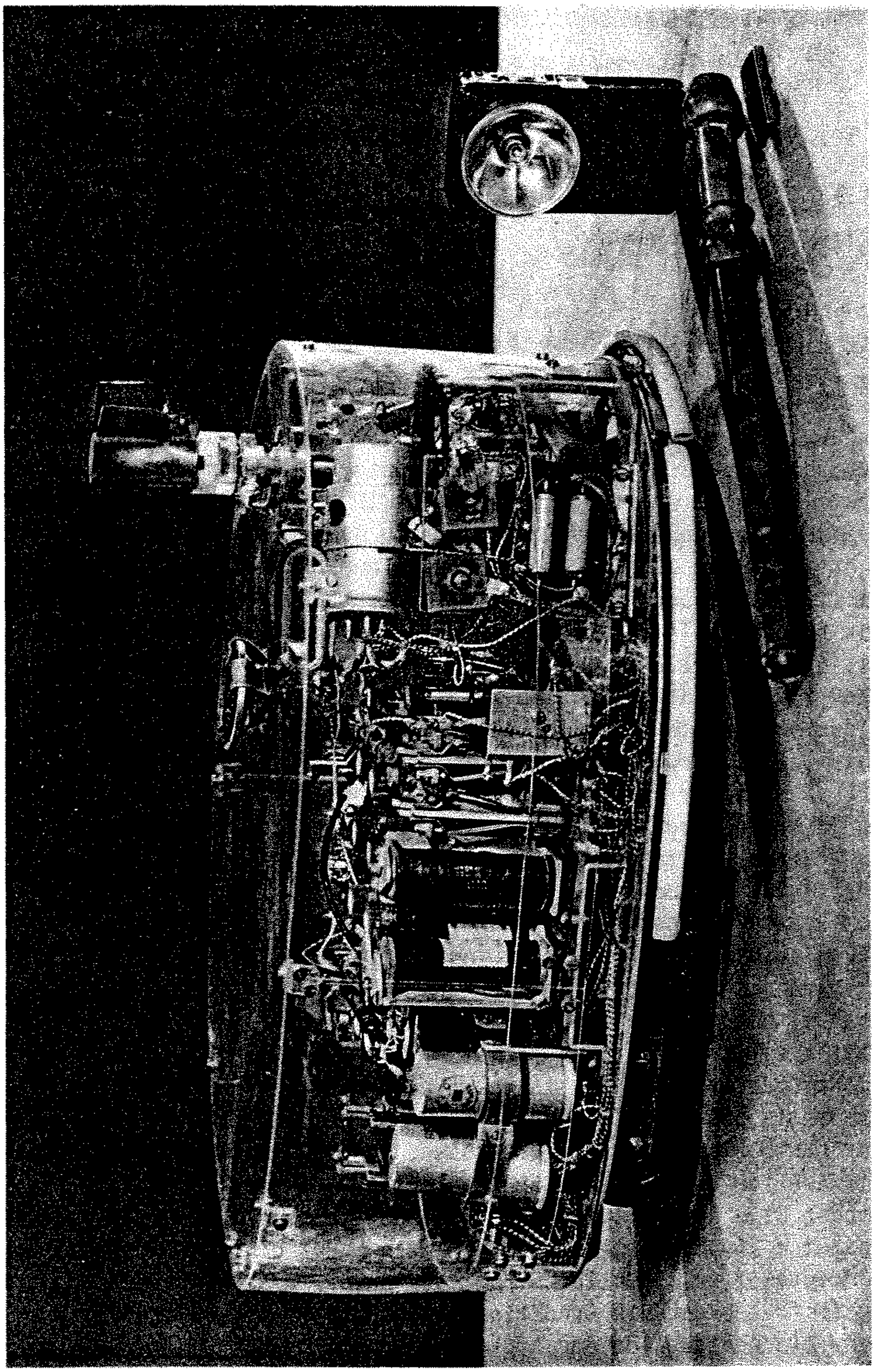

Fig. 1

The model has two or three receptors, for light, sound, and mechanical input. The signals from these receptors are relayed through two control "centres" each of which controls a motor; this dichotomous control serves to demonstrate a basic innate pattern of behaviour. (There is in fact a very important dichotomy inherent in all behaviour, between *well-oriented and directed goal-seeking and random searching.)*

Like most living things, the model, if once aroused, searches for a goal for one of its tropisms or inborn unconditioned reflexes. It searches for light because of a connection between its photo-receptor and effector motors. This behaviour, which is dominant in the system, is disturbed or inhibited by any other stimulus impinging on its mechanical or acoustical receptor systems.

But extreme strength or duration of the original dominant stimulus causes the model to seek a new dominant cue. This illustrates another principle of reflex activity which never allows an organism to follow any drive continually: by switching off the drive at some level or after some time it starts a search for a new stimulus. Analogies of this can be found both in whole organisms and in any artificially separated part of their nervous system. Two teleological principles seem to be involved, but by introducing the concept of positive or negative feedback the organization can be seen to be very simply determined.

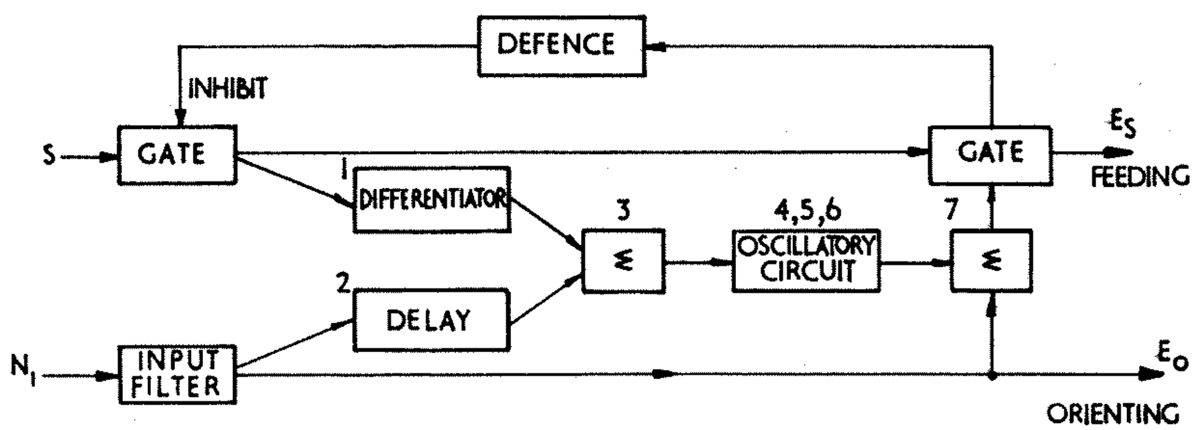

Fig. 2

A logical concept of *conditioning and learning* was built up by Dr. Grey Walter in his 'CORA' and we must study the action of 'CORA' briefly before going on to the next stages. *Figure 2* is a block diagram drawn in similar form to Machina Reproducatrix. The first three logical elements of Dr. Grey Walter's model can show a behaviour analogous to that which may happen in every instant of alert activity of the brain centres. Two stimuli, which originally were temporally or spatially separated, may meet on one or more synapse of the brain, ensuring alertness which is a basis for receiving communications from the external world. In 'CORA' this can happen if (a) the original driving or tropistic stimulus is differentiated(1)* corresponding to the on-off effects produced by appropriate synaptic connections at sensory inputs to the brain. (b) a second non-dominant or neutral stimulus preceding the dominant one is delayed in its effect(2) (corresponding to "after discharge" or widespread non-specific activation of synapses). (c) the two signals satisfy the necessary conditions, e.g. coincidence, summation(3).

So far there are no difficulties in explaining these features of neuron behaviour, but for building up a conditioning process a further logical step has to be introduced. This involves a temporal summation of the overlapping coincidence areas or the probabilities of the two stimuli. In the model this can be represented quite simply by a capacitance circuit(4); nevertheless in a nervous system it may involve a more refined mechanism e.g. it may work on principles similar to Dr. Uttley's conditional probability system.

Dr. Grey Walter points out that a nervous system, working as a learning box must rule out sheer chance and reach a threshold of coincidence for conditioning. There have been many hypotheses of conditioning, e.g. in the neurophysiologically almost correct work of Eccles (*ref. 6*) he attempted to localise it as a specific feature of the central grey matter or of the cerebral cortex because of the multitude of input and output connection in this region. But Pavlov pointed out (*ref. 17*) that in appropriate conditions the "Summation reflex" (i.e. association of two stimuli) may occur and give effects on any level of the nervous system, especially the less co-ordinated ones. Dr. Uttley (*ref. 19*) found that, in his conditional probability computer, the activation of a unit corresponding to the firing of a neuronal network does not suffice to distinguish actual occurrence from computed probability, and he introduces the postulate for a regenerative loop.

The next steps in Dr. Grey Walter's logical scheme are activation(5) and the preservation(6) of information by an oscillatory circuit with very light damping (an analogy of cortical alpha-rythym). These steps are

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* Numbers in brackets refer to points on the block diagrams.

followed by gating[7] the oscillation and the original neutral stimulus to produce a response corresponding to the original dominant or unconditioned stimulus. The response is analogous with cortical neuron output.

At first glance this seems to be a correct representation of conditioning and of the memory function of the brain and *most hypotheses explaining conditioning on the basis of neural connections are similar.*

We decided, in our model Machina Reproducatrix, to reproduce conditioning in the same way as 'CORA' does, but instead of an oscillatory circuit we employed a neon tube with two relays and a thermistor (the slow rise of temperature of which produces a memory for paired stimuli for almost the whole running period). This solution was preferred since the original one was too sensitive to mechanical disturbances. This may also be said about the neural network which is exemplified by this circuit. In the introduction of the thermistor we may see a very slight analogy with the newly-established fact that the excitability and activity cycles depend on the activation system and thence the cortex on vascular effects. There is so far no justification for taking these analogies too far.

Though Dr. Grey Walter's learning box displays some surprisingly correct imitations of life it shows that *until the last few years the explanation of brain processes in conditioning and learning followed a very simple scheme.* Compared with any animal during conditioning, we must conclude that the CORA circuits omit some important characteristics. These are:-

(a) the conditioning trials do not lead to habituation of the neutral stimulus,

(b) other stimuli related to the conditioned one produce no effect, i.e. no generalization occurs.

(c) memory is lost as the oscillations gradually decay in the memory circuit and is finally extinguished. We must repeat the stimulus combination to obtain recovery which is never spontaneous as it is in animal conditioning experiments,

(d) a new disturbing stimulus may cause gross deficiencies in the function of such a delicate automaton depending on external influences. They seem to produce neurotic-like behaviour, but no marked external inhibiting or disinhibiting effects can be distinguished.

We therefore attempted to supplement CORA to overcome some of these defects. Machina Reproducatrix responds to three stimuli, light, flute and whistle. Six or eight repetitions of flute and light cause conditioning and the model turns it front towards the sound (just as the previous model did to light). But once the capacitive memory sustained by the thermistor circuit decays, no more conditioning effects are observed. If we repeat the combination of flute plus light conditioning occurs at once. If we now try the whistle, we may observe a conditioned effect i.e. a *generalization.*

But after several (about 18) repetitions of whistle without light no more such effects occur, whereas the flute (which with light was the original stimulus) remains a conditioned stimulus. This is simple *discrimination* and if we carry on fluting only, the effect of the flute is also extinguished or habituated and no tropistic behaviour is seen. But, in our model, the conditioned effects of the flute recover in a few minutes, but the whistle remains as an effectiveless stimulus. If a new sharp sound is intonated, even the flute may be depressed; this is *external inhibition*, and after a few instances the whistle will regain its effect, this is disinhibition. The flute also recovers its conditioned effect comparatively soon.

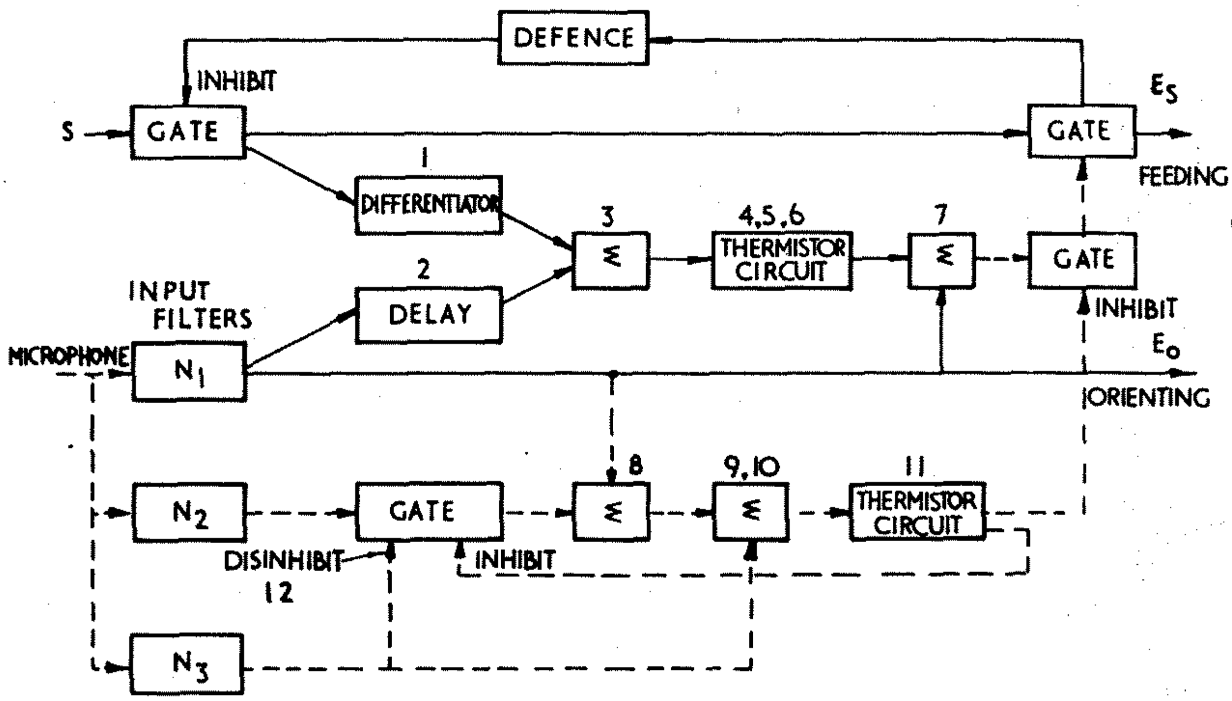

Fig. 3

Figure 3 is a block diagram of the original model, Machina Docilis, and the supplementary parts which have been added to make Machina Reproducatrix achieve these features. The three inputs N_1, N_2, N_3 have a common input to a counting device[8] connected with another thermistor circuit[9] [10] [11], the outputs of which are connected to the gating relay. If N_1 and N_2 occur together conditioned reflexes are obtained from any input which contains either, but stimulations due to N_1 or N_2 alone are counted and cause blocking for a given time of the conditioning effects. If a sufficient number of unpaired stimulations of N_2 occur it leads to permanent inhibition of unreinforced stimulations of N_2 until N_2 is disinhibited. Thus we build up a discrimination. If a new stimulus N_3 is given, and it is strong enough, it connects a transistor circuit to produce disinhibition of N_2 and also inhibits the conditioning effects of N_1.

We realise that this model is somewhat crude, but it was conceived not only for demonstration purposes, but also to draw attention to some important questions. The supplement to "Machina docilis" was conceived to represent the phenomenon of *habituation* which results from any biological stimulus. It is a basic mechanism by which extinction of conditioned reflexes and their internal inhibition leading to discriminations is built up physiologically. But its effect is temporary, and may be thought of as a negative feedback to the changes in neural connections of every nervous adaptation. In fact, the conditioned reflex cannot be fully represented by taking account only of association, combination or summation of two stimuli, since the mechanism of habituation occurs in parallel and counteracts any accumulation of corrections. (Thus, it ensures the conditions necessary for the coexistence of a "conditional probability" and a "conditional certainty" system in the brain). Experimental observation on the mammalian and human brain especially in the Neurophysiological Institute of Pecs and also in the Neurophysiological Clinic in Debrecen, (Lissak and Grastyan *ref. 12*, Kajtor et al, *ref. 10*), clearly suggested that it is the hippocampal system which may act like a counting device for any sensory inputs. This agrees with Green and Arduini's electrophysiological observations. They observed that, following stimulation, the hippocampus may inhibit conditioned reflex activity, independently of the origin and dominance of conditioned or unconditioned stimulations, and this may be demonstrated by studying orientation reflex phenomena of the model. Now it seems that the supplementary parts of the model may be compared with the negative-feedback effect which the hippocampus has on neocortical and brain stem phenomena in conditioning. We should leave further neurological discussion of the structural analogy and point only to some observations by which the validity of this analogue can be tested. The electrophysiological observations of Morell, Jasper et al (*ref. 15*) have shown that a significant impairment of electrocortical conditioning occurs only with archipallial (hippocampal) lesions and Penfield and collaborators (1958, *ref. 18*) pointed recently to the fact that distinctive, bilateral lesions of the hippocampus only wipe out the recollection of recent memory experiences. But even if we control the effect of such lesions or that of any extended cortical lesion in a conditioned reflex experiment, we may find that the association process by itself is less impaired than discrimination and appropriate recall (Angyan, 1956, 1957 *ref. 2*). This somewhat too docile impaired learning mechanism is modelled by "Machina Docilis". We get the same result by comparing the brain adaptation with any model taking account mainly of the conditioned summation reflexes.

Our model demonstrates (1) that habituation and internal inhibition must occur *in parallel* and must to some extent inversely regulate the conditioned summation or probability computation process. (2) that *discrimination* is based on a *common mechanism with habituation* but it may be further improved if specific inputs with specific analysing mechanisms are considered. Some degree of discrimination may be obtained by filter mechanisms, but it is only effective if it is regulated by extinction based on habituation. (3) that *spontaneous recovery* (or recall of *forgotten or extinguished* conditioned reflex) cannot be based on preferential states for more recent stimulations (as in Dr. Uttley's concept). Our model though far from being a sufficient analogy, allows the repeated recall of an extinguished conditioned reflex during the whole span of its memory.

The fact that our model is still of insufficient complexity is shown by the effect of external inhibition. By causing a block through the orientation-habituation mechanism, this wipes out both the effects of positive and negative stimulations. To obtain a recovery of discrimination, we need to build up again the extinction or discrimination process. In our opinion, this problem can be adequately developed by constructing a model which incorporates *another* very important and experimentally well-founded fact of nervous adaptation - the Sherrington principle of *reflex antagonism* and mutual induction. Pavlov has pointed out that this is the third basic mechanisms (with excitation and inhibition) in the maintenance of dynamic equilibria of every complex of innate and acquired behaviour.

If we assume that, in parallel with the extinction process or the development of any internal inhibition, that the stimulus to be discriminated build up a connection with another specific stimulus in opposition to that already conditioned (e.g. summed with a negative stimulus), it would not be too difficult to build a model which demonstrated electronically this mutually or reciprocally inductive antagonism (perhaps in the sense of Wiener's 'moth and bedbug' model combination). If the two summation systems are coupled together mutually in an inverse feedback manner, an automatic mechanism is obtained which resets the original state of discrimination immediately after the disturbing stimulus disinhibited it. In fact, this occurs in uninjured, normally adapting, animals, with a speed and repeatability which is very characteristic of the individual. It is one of the most important transformations which sometimes seems to almost entirely override the rules of conditioned association in everyday psychic activity. It is usually the first mechanism to be impaired following functional or structural disturbances of the brain. We are convinced that this mechanism of 'direct' inhibition is an inherent structural feature of nervous organization. Every unconditioned reflex has a positive 'to' and a negative 'fro' aspect (seen in defence, feeding and sexual activities). These form the basis of unconditioned reflexes in their lower and higher manifestations.

Plasticity (acquired individual adaptation) is however maintained by habituation, or by indirect inhibitory mechanism, which never allow 'summation reflexes' to build up above a certain limit on the basis of the former ones as a result of new stimuli impinging in their networks. Plasticity also counteracts the development of fixed correlations between the summation reflexes, in contrast, e.g. with the spinal cord's reflex organization. In an ideal model system which also contains the development analogies it should be shown, as in the mammalian brain and in general in animal of the main philetic line, that (a) these mechanisms are acting along spatial axes according to Child's gradient (b) the habituation mechanism in its interaction with a summation of probabilities is never allowed to be static (c) the opposing coupled basic reflex systems cannot be static. If it satisfies these conditions the model system fulfils the requirements of Dr. Ashby's concept of homeostatis maintained by ever-changing dynamic equilibria and regulated by partly deterministic and partly probabilistic percetion systems. But our supplemented model has functional correlates in the high organization level of the mammalian brain. The dichotomy of its design is also based on simple experimentally-demonstrable properties of neurons just as in the hypothesis of Eccles - *impulse treshold changes, synaptic use and disuse, reciprocal antagonism and feedback principles.* There are also probably differences in the axosomatic and axodendritic connection of neuronal adaptation similar to those of summation and habituation on the higher organizatory level.

CONCLUSIONS

Our model cannot exclude the possible generalization that learning is simply due to a coupling of two mechanisms - say a positive or excitory feedback and another negative feedback on inhibition. This coupling can occur at every structural level of biochemical, electrophysiological, or functional anatomical organization, and to show its special adaptive features we must find out the principles for further development which are directing the mechanism whose nervous system quickly adapts to its environment. Recent observations of the author (Angyan et all 1957, 8 *ref. 3*) on the behaviour of flatworms during regeneration of the cephalad and caudad parts of their primitive nervous system shows that the two aspects of nervous function referred to above may be separated from each other functionally and structurally by simple experiments. It seems that both developmental and behavioural mechanisms show interesting polarization along the developmental axes of Child's gradients. Perhaps the conditioned reflex is no more than a temporal expression of an axial developmental mechanism propelled by an excitatory summation which shows more general rules of polarization and is limited by inhibitory habituation.

Since in complex organisms we are dealing with at least three special dimensions or axes (and perhaps a temporal one as well) we are inclined to suppose that a more complete analogy of learning and conditioning would be represented by a model in which three antagonistically-coupled CORA or Reproducatrix systems were linked and their varying dominance cancelled by an adequate internal scanning or temporal summing mechanism. This idea forms the basis for further development of our model (Angyan, Zemanek and Kretiz, 1959).

In our opinion, models are only useful in that they help to draw a better concept of present knowledge of brain function the realization of which may show whether our ideas and terms may correspond or should be excluded from the interpretation of life.

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THE CONDITIONAL PROBABILITY COMPUTER

by

DR. A. M. ANDREW

THE Conditional Probability Computer constitutes a versatile "learning machine". It simulates certain features of animal learning and embodies principles which are important in the development of adaptive control mechanisms for industrial applications. A brief account of the operation of the computer is given below, followed by descriptions of the particular applications demonstrated.

Conditional Probability Computer

The computer shown has five input channels labelled j, k, l, m, n, but computers with any number of input channels are possible in principle. It consists of 31 similar units which count the number of occurrences of the patterns of input activity presented in these channels. When some statistical data has been accumulated, and when one or a group of the input channels is activated, the computer determines, on the basis of its stored statistical information, whether this group is usually accompanied by activity in another channel or channels. If it is, the computer makes an *inference* of activity in the other channels (shown by *red* illumination of the panel above the computer). The precise conditions for an inference are described below.

The 31 units are essentially counters; five of them count the numbers of occurrences of activity in the respective input channels, while a further ten units count the numbers of occurrences of simultaneous activity in each of the ten possible pairs of input channels, and so on for groups of 3, 4 and 5 channels. The counts are represented in the units by the amount of charge on a capacitor, which is deliberately made to leak towards the level corresponding to zero count. The introduction of leakage ensures that the inferences made by the computer are governed more by recent events than by less recent events.

The conditional probability of activity in the l channel, given that there is activity in the j and k channels, is given by:

$$p_{jk}(l) = \frac{\text{count stored in } (jkl) \text{ unit}}{\text{count stored in } (jk) \text{ unit}}$$

Whenever the j and k inputs of the computer are activated simultaneously, it computes the quantities $p_{jk}(l)$, $p_{jk}(m)$ and $p_{jk}(n)$. If any of these exceeds a predetermined threshold value, an inference is made of activity in the l, m or n channel. The operation is similar when other groups of input channels are activated.

A SIMPLE COMPUTER FOR DEMONSTRATING BEHAVIOUR

by

DR. W. ROSS ASHBY

SINCE any imaginable behaviour of a system can be represented as a sequence of transitions from state to state, any behaviour can be represented isomorphically on a machine if the machine is designed or programmed to perform the appropriate transitions.

The demonstrated machine has a set of states (lamps lit or unlit) and a set of input states (switches open or closed.) When the handle is given one turn (representing the passage of one unit of time) it will change to some state that is a determinate function of what state it is at now and of what state is (at the moment) on the input. Repeated turning of the handle will thus generate a sequence of states, i.e. a trajectory, or line of behaviour.

Abstractly, it may thus be described as a machine that, with a set I of input states, and a set S of system states, can be programmed to give (within limitations of size only) any desired mapping of I x S into S. *Which* mapping is to be used is controlled by a plug-board. A particular setting on the plug-board makes it (functionally) a particular machine with input, with a particular way of behaving and of responding to stimuli.

Its chief use is the purely illustrative one of demonstrating how various forms of behaviour that are well known in the biological world appear after they have been analysed in accordance with the logic of mechanism and behaviour. It is especially suitable as a teaching device for making clear the principles of mechanism and of Black Box theory *(ref. 1)*.

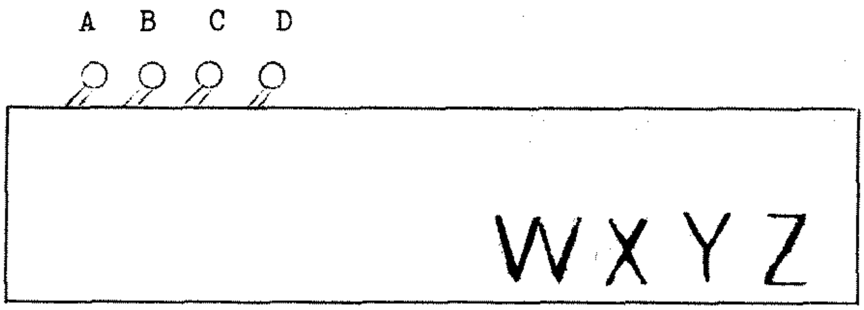
Over forty well known pieces of biological behaviour (often simplified for reasons of size) have already been programmed on to it. They include:-

Simple reflex with sustained response (e.g. the pupillary.)
" " " transient " (e.g. the knee-jerk.)
" " " latent period.
Accumulation of drive.
Displacement activity.
Response only to a pattern.
" " " patterns of particular type.
" " " a sequence of patterns.
Conflict leading to oscillation.

Conflict leading to compromise.
" " " "catatonia", with protection and cure.

DEMONSTRATION

The demonstration set up for the Symposium shows the last named. The behaviour may be thought of as analogous, in animals and man, to certain reactions evoked by situations or stimuli that arouse conflict between two ways of behaving.



The system's resting state is with lamp X lit. If switch A is closed, the lighting moves over to W (as if drawn by A.) If switch C is closed, the lighting moves over to Y. Repetition of A and C shows that the system's responses are regular and reproducible.

To B and D it gives no apparent response.

If now A and C are put down together (so that if the system were living we might say that the light was in a conflict about whether to go to the right or left) then the system responds by generalised extinction. No further stimulation by A or C (even if applied singly in the normal manner) can elicit any further response from it. Application of B does nothing to change the situation.

Closing D, however, has a "curative" effect, for subsequently the original behaviour is restored.

B, however, is not wholly without effect; for if the conflictful situation (of A and C being presented simultaneously) is combined with the application of B, the extinction does not occur.

Thus the behaviour shows the features that:-

(1) The effect of applying stimuli A and C simultaneously need bear no natural or simple relation to their effects when applied separately.
(2) A transient event (the simultaneous application) may have lasting effects.
(3) Other actions on the system (closing B or D) may have a "preventive" or "curative" action. The one action does not imply the other.
(4) A variety of other deductions could be made.

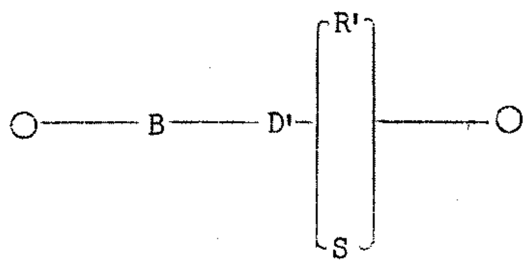
EQUIPMENT

The machine uses relays, whose power comes through their own contacts so as to make them self-locking.

During one cycle of the handle, the first quadrant makes contacts so that the states of W, X, Y, and Z are copied on to other relays P, Q, R, S. W, X, Y, Z are then cleared. Then power is applied so that (e.g.) W is energised if and only if a way exists through the network on the plug-board, which tests various series and parallel combinations through the contacts of A, B, C, D, P, Q, R, and S. Thus if W is to become energised if and only if:

(1) B is energised,
and(2) D is not energised,
and(3) either R is not energised or S is energised,

then the plug-board would use the net



(where a prime indicates a break-contact.) Similarly, three other networks control X, Y, and Z.

Once the behaviour is clearly specified in a canonical representation, the arrangement of the plug-board can be found by a purely formal process (i.e. calling for no further insight.)

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AUTOMATIC PATTERN RECOGNITION

by

DR. W. K. TAYLOR

The demonstration illustrates the method of constructing pattern recognition machines described in Paper 5 of Session 4B. To obtain the highest character recognition speeds that the networks are capable of it is necessary to use a parallel input system such as a 9 x 9 matrix of photomultipliers. The speed can then be up to 10^6 characters per second in a practical system, since it is only limited by the finite rise time imposed by stray capacitance. Photomultipliers are expensive, however, and for the purpose of demonstration a similar set of signals are obtained in approximately 1/50 second by arranging for the single output of an electromechanical scanning system to charge a matrix of capacitors to voltages that are proportional to the light flux falling within corresponding elements of the image. The characters to be recognised are typed by a standard typewriter and illuminated by a spotlight. A small lens projects an image of the character onto a perforated scanning drum and the light passing through the holes is converted into a voltage by a single photomultiplier. This voltage is connected to the matrix of capacitors through a synchronous switch and after one revolution of the drum the capacitors are charged to the appropriate voltages which are called x-signals in the paper.

In designing the demonstration machine a letter A was typed onto the paper and adjusted to be within the field of the scanning system. The x-signals were then measured with a voltmeter and the set of signals that gave the largest value of y in equation (1) was easily determined by combining them in order of magnitude. A y-signal network was then constructed as shown in *Fig. 3* by connecting resistors to the bus-bars that correspond to the required set of x-signals. It should be noted that this procedure could have been repeated with the letter A in a set of sample positions within the field of the lens, which is approximately 20% larger than the letter. The number of samples required to give recognition of the A in any position is not large since the x-signals do not change appreciably until the letter moves through a distance of one matrix element. In *Fig. 1a*, for example, the A can only occupy approximately

10 discriminable positions and by constructing this number of y-networks the machine would operate correctly with the A in any position. The extra expense involved in having a number of y-networks for each character is negligible since the resistor networks can be produced very cheaply in a printed circuit form.

In the demonstration apparatus there is only one y-network for each character and in consequence the alignment has to be preserved to within approximately half a matrix element. The mechanical accuracy of the typewriter is within this limit.

By repeating the design procedure for B, C and D the apparatus reached the stage shown in the demonstration. Unfortunately time did not permit the construction of y-networks for the entire alphabet but the 19" x 30" x 10" cabinet contained ample space for them, in addition to the 26 output stages and amplitude filters.

For applications such as computer read-in and letter or cheque sorting the only output required is the closure of a different electronic gate or switch for each character or pattern class. In the demonstration model the output switches select recordings of the letter names from magnetic tape. Thus as each letter appears under the lens it's name is reproduced through a loudspeaker. By extending the size of the input system n-times in the direction of writing it would be possible to accommodate words of up to n-letters and hence to produce a realistic reading machine. The speed would be limited by the rate at which recordings of the words could be selected from the store and a special parallel recording system giving rapid access would be desirable.

LIBRARY RETRIEVAL*

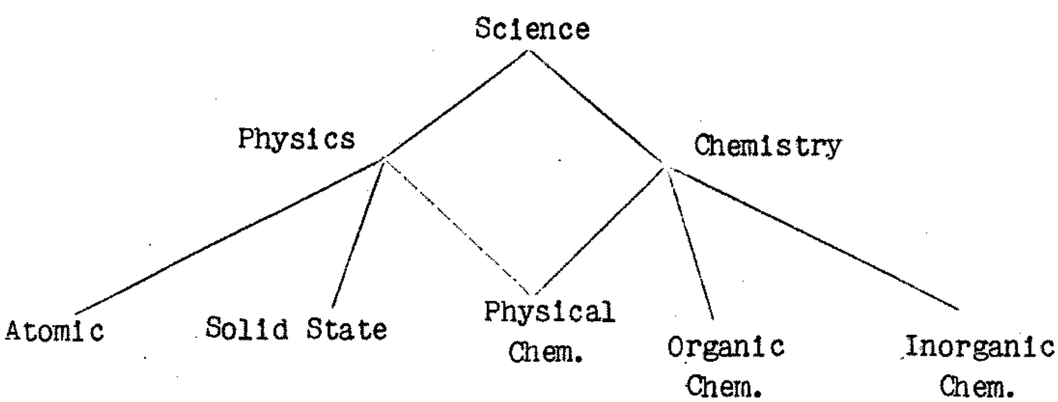
by

S. WHELAN

1. INTRODUCTION

The object of a retrieval system is to organize the indexes of a collection of documents in such a way that any documents requested can be found algorithonically.

Undoubtedly the simplest form of retrieval system is the ordinary alphabetical index. Where small collections of documents are involved, such a scheme works moderately well - most office filing systems are of this kind. However, such a method is of little use when dealing with large collections (say 50,000 documents), for then each letter of the alphabet will have coded under it a large number of documents and to retrieve any one document from the sub-collection associated with any one alphabetical letter will need some further retrieval system and, hence, some modification of the original alphabetical index is necessary. As the library grows (and libraries do!) the modifications super-imposed on the original (relatively simple) system will be such as to complicate the system and lead to more sophisticated retrieval methods such as the Universal Decimal System (UDC) for example. Despite apparently superficial differences, all such methods have one thing in common. They treat the subject matter of the library (field of knowledge) as being capable of subdivision into a tree-like structure; thus, e.g.:-

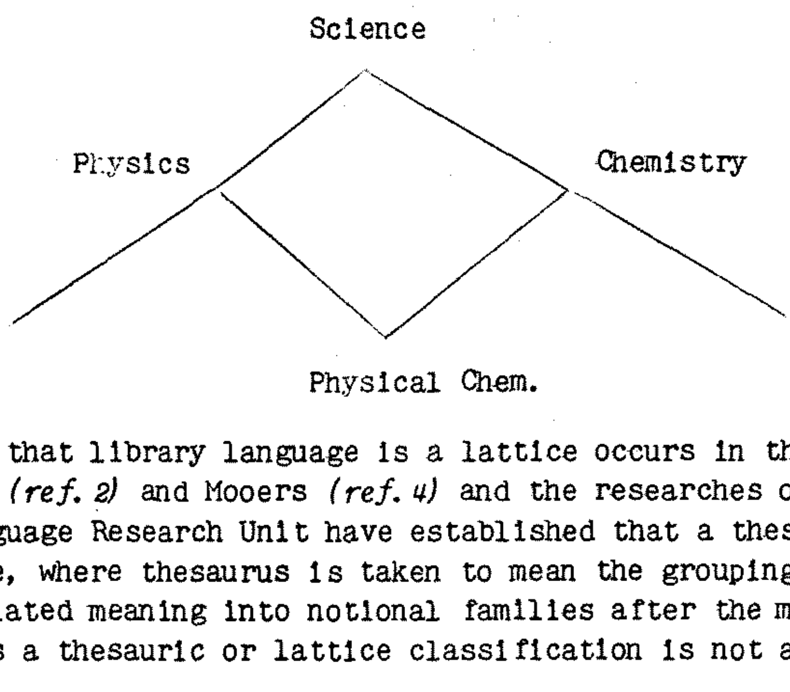


* Reprinted from R.R.E. Journal, Oct. 1958.

Such a subdivision is essentially arbitrary and becomes more so as the library grows. After only two subdivisions we are in difficulty straight away. How, for example, are we to classify a document on Physical Chemistry? Do we classify it under Physics or under Chemistry? Does it deal with Physics in Chemistry or Chemistry in Physics? At the very start, a decision of some sort is forced upon us. This would not be too bad if, having made the decision according to some principle or other, we could be certain that when a similar decision is to be made in the future, it will be made in conformity with the same principle. Unfortunately there is no procedure which can guarantee such conformity. Indeed there cannot be, for it would be impossible for any principle or procedure to take account of all the consequences inherent in arbitrariness.

Various subterfuges are introduced to overcome such difficulties but they end by making the system they were designed to correct unwieldy and, in some cases, unmanageable. The net result is that, sooner or later, such systems fail to retrieve wanted information and, very often, a high percentage of the library's documents are effectively lost. As far back as 1945, Dr. Vannevar Bush *(ref. 1)*, when reflecting on this matter remarked, "Even the modern great library is not generally consulted...... our ineptitude at getting at the record is largely caused by the artificiality of systems of indexing".

The question arises, therefore, as to whether there is any other structure which will enable us to code Physical Chemistry under both Physics and Chemistry, which is logically where it ought to be coded instead of under either. The answer is that there is such a structure - a lattice, thus:-



The notion that library language is a lattice occurs in the writings of Fairthorne *(ref. 2)* and Mooers *(ref. 4)* and the researches of the Cambridge Language Research Unit have established that a thesaurus is also a lattice, where thesaurus is taken to mean the grouping of words of similar or related meaning into notional families after the manner of Roget. In other words a thesauric or lattice classification is not arbitrary.

2. THESAURUS

By 1955 RRE felt that Retrieval Research for the most part was doing little more than invent systems which, while certainly an improvement on existing systems, did not materially differ from them and, in any case, were not sufficiently fundamental. It was this consideration together with the intrinsic merits of the scheme which decided RRE to adopt what is essentially a thesaurus approach and to embark on a pilot experiment designed to test this approach. The RRE scheme consists in choosing a limited number of basic or elementary terms (100-200, say) which, both singly and in combination, cover the subject matter of the library of documents. These terms should be as fundamental to the library as possible - indeed its ultimate constituents. They need not even be dictionary words, but it follows that they will be as exclusive as possible. The exclusion property follows from the lattice property of the thesaurus but it can also be argued from first principles. For, if an additional term is added to a list of thesaurus heads and if this additional term can be accounted for by a combination of one or more existing heads then, clearly, it is not a head. Choosing these heads (terms) is not easy; nor is it clear on what general principle it should proceed - still less is it clear whether the process could be mechanised by, e.g., machine searching of dictionaries. Obviously synonyms and near synonyms would be grouped in the same head, as would also words of cognate meaning such as - e.g. - "export" and "import". In this way we avoid the risk of non-retrieval of, e.g., a document on "Imports to Y from X" when the enquirer wants documents on "Exports from X to Y". We can always choose heads to ensure that the system discriminates to any extent we wish and the RRE scheme further ensures that the frequencies of recurrence of the heads are contained within certain limits (referred to as bandwidth). Clearly "electro-magnetics" is far too general a head for a library dealing with electromagnetics.

Furthermore the thesaurus must be constructed before embarking on the experiment. Indeed the system would not be thesauric if the terms (heads) are allocated after reading documents. This latter scheme would be more like Uniterm.

The following more or less random sample of terms used in the RRE experiment shows the scheme to be a thesauric one:-

No.	*Head* *(Synonyms, Cognate words etc.)*
2	Add (gain, superimpose, sum, application, join, towards)
10	Calculate (compute, analog, digital, count, enumerate, numerical, determine, estimate, value, error)
28	Generate (excitation, construct, make, produce, prepare, design)
37	Macro (large, excessive, increase, amplify, wide)
73	Star (solar flares, prominences, eclipse, meteors, sun)

Should the library extend in some unforeseen way either by storing books on some completely new subject or books on a subject not new, but which the library did not hitherto deal with, then it is always possible to add to the list of heads. The RRE scheme uses 75 heads. In practice, assuming one has a fair knowledge of the library to be coded, it is not difficult to discover the first 20-30 heads. To arrive at more is usually a difficult procedure. Another possible way is to make a library lattice, which is what the members of Cambridge Language Research Unit have done. Either way the task is not easy.

When the list of terms is complete they are then placed in some convenient order (RRE uses the alphabetical order). It is to be remembered that there is no essential significance - beyond one of mere convenience - attached to this ordering of the terms amongst themselves. When ordered, the terms are now numbered from zero upwards. This list of numbers (heads, terms) is now used to code the documents for storage and subsequent retrieval.

3. CODING, STORAGE AND RETRIEVAL

The document to be stored is given an accession number, read and abstracted.

(a) *Coding.* To facilitate the operation of the scheme, (even by persons unacquainted with its basic principles), an alphabetic dictionary of terms which occur in the reports and in the library requests has been compiled. These terms give reference to as many of the listed thesaurus heads as is necessary. Consequently, when a report is abstracted, the numbers associated with the heads which cover its subject matter are noted. This may be done either by reference to the list of heads or, more easily, by reference to the dictionary.

(b) *Storage.* Metal plates (about 14in. square), capable of being punched with 10,000 holes each, are used for storage. There are as many plates as there are thesaurus heads and the coordinate position of a hole in a plate represents the accession number of the document being stored. If, for example, the document to be stored has an accession number 509 and the heads number 5, 17, 24, 36, 61, 83 cover its subject matter, then the plates corresponding to heads 5, 17, 24, 36, 61, 83 have each a hole punched in the 509th position.

(c) *Retrieval.* To make retrieval easy and speedy all the plates are stored together and each plate has a tag on it which is easily visible and identifiable and which bears the number of the thesaurus head to which it corresponds. A request for a document is broken down into the heads which cover its subject matter (again, either by using the list of heads or by means of the dictionary), and the plates (heads) which apply to the document in question are then pivoted about one end, thus bringing them simultaneously in register in front of a parallel beam of light; clearly the document having the hole (and hence the accession number) common to all the plates is the document sought after. More sophisticated means for reading the coordinate positions of holes easily suggest themselves.

4. EXPERIMENTAL RESULTS

A first experiment on a very small (randomly chosen) document-sample (110 reports) gave 100% success and encouraged us to increase the sample to 1000 documents. These 1000 documents consisted of documents currently received at the RRE library. The fact of currency eliminated bias in choice and so the sample can be regarded as sufficiently random.

Several lists of questions were prepared to test the scheme. The lists were prepared in the following way. A list of the titles of the documents in the sample was handed to members of the library staff who were asked to compile requests similar to the requests the library usually receives. The requests were to have no more vagueness or precision than the usual library request. Typical questions asked were on such subjects as: Butterfly Circuits, Brightness of the Atmosphere, Properties of Oxide Cathodes, etc. (see Appendix 1, which gives a sample extract from the experimental results).

In all cases where the request was moderately specific the document in question was retrieved without any unwanted or irrelevant material. As the precision of a request decreases, giving way to vagueness, then the document or documents in question are still retrieved, but so also are other documents in descending scales of relevance corresponding to the increasing scale of vagueness. This, of course, is what one would expect a thesaurus retrieval system to do and it becomes more clear when one regards the thesaurus as a lattice. For a thesaurus system will always retrieve something and this something will be what is most relevant to the request *(ref. 3)*. The interesting result is that the relevant material is always retrieved. In the RRE scheme the worst proportion of relevant to less relevant materials was found to be of the order 1:3 and this only in cases of extremely vague requests. In no case did the system fail to retrieve the wanted material. While perfection is not claimed for the RRE thesaurus, it gives an amazing degree of success (see Appendix 2).

5. CONCLUSIONS

The research makes clear that the thesaurus approach to information retrieval is the most promising approach made so far. The theoretical and experimental fact that it always retrieves the material most relevant to a request is the best guarantee of this approach. It means that none of the library's material is ever 'lost', as indeed a fair proportion of it is when other retrieval systems are employed.

From our studies we are convinced that any further research on retrieval will have to proceed along thesauric lines if any worthwhile results are to be obtained. Nor is there any objection to extending the scheme to cope with the largest libraries. A larger thesaurus (lattice) will, of course, be necessary and obviously the scheme would have to employ digital computers but the rules for finding the elements of a lattice are precisely the rules which computers are designed to obey.

6. ACKNOWLEDGMENTS

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APPENDIX 1

Question	Degree of precision	No. of reports retrieved	No. of relevant reports	No. of irrelevant reports	No. of relevant reports in sample	Ratio of irrelevant to relevant reports
Luminescence of Metallic Salts	Precise	1	1	0	1	0
Post War Structure of Ferromagnetism	Very Vague	3	1	2	1	2
Butterfly Circuits	Vague	1	1	0	1	0
Technical Writing	Vague	4	1	3	1	3
Earth Conductivity	Vague	2	1	1	1	1
High Vacuum Techniques	Vague	3	1	2	1	2
Frequency Converter	Very Vague	35	9	26	9	2.88
Metrology	Very Vague	27	12	15	12	1.25
Welding Techniques	Vague	24	6	18	6	3
Potential Divider	Vague	7	2	5	2	2.5

APPENDIX 2

No.	Head	(Synonyms, Cognate words etc.)

1. Accoustics (tune, resonate
2. Add (gain, superimpose, sum, application, join, towards
3. Air (meteorology, climate, climatology, cloud, wind, storm, gas, sky
4. Angle (phase, angular, corner
5. Anti (opposed to, prevent, prevention, not, non-
6. Array (shape, pattern, matrix, arrangement, structure, lattice
7. Attenuation
8. Auto (automatic, self
9. Bend (reflection, refraction
10. Calculate (compute, analog, digital, count, enumerate, numerical, determine, estimate, value, error
11. Change (alter, different, alternate
12. Characteristics (properties, parameters
13. Circle (wheel, rotate, ring, annular, cyclic
14. Component (element, part, factor, unit
15. Constant (stable, stability, permanent
16. Control (servo, feed-back
17. Defence (flight, military, gunnery, attack, tactics, tactical, strategy
18. Electric (current, conductivity
19. E.M. above 10 cms (Above 3000 Mc/s))
20. E.M. 10 cms. - 1 cm (3000 - 30,000 Mc/s) } Electromagnetic
21. E.M. 1 cm - 1 mm (30,000 - 300,000 Mc/s)) Waves
22. E.M. below 1 mm. including IR and beyond)
23. Equal (equation, equate
24. Equipment (apparatus, instrument, set, machine, mechanical
25. Explode (bomb, burst, blow-up, projectile, weapon, missile
26. Foreign (various countries
27. Function (purpose, use
28. Generate (excitation, construct, make, produce, prepare, design
29. Ground (land, sea, horizon, earth, cosine
30. Height (elevation, sighting, perpendicular, vertical, sine
31. Infrared
32. Integral (differential
33. Jam (interference, RCM
34. Limit (finite, test, trial
35. Line (linear, direct, length, axis
36. Locate (find, position, scan, plot, search
37. Macro (large, excessive, increase, amplify, wide
38. Magnetic (magnet, magnetostriction, solenoid
39. Material (metals, non-metals, mass, resins

No.	Head	(Synonyms, Cognate words etc.)
40.	Measure	(correct, adjust, assess, calibrate, verification
41.	Micro	(miniature, small, narrow
42.	Movement	(transport, transportability, mobile, shift, dynamics, displacement
43.	Multi	(combine, synthetic, many, cascade, mixture
44.	Name	(proper names - e.g., Geiger-Muller
45.	Network	(circuit
46.	Operator	(operation, human
47.	Particle	(nuclear, atomic, electrons, molecules
48.	Point	
49.	Positive	(improvement
50.	Power	(energy, strength, voltage, force, tension
51.	Practical	(experimental, performance, method, maintenance
52.	Probability	(statistics, random, chance, noise
53.	Propagate	(mode
54.	Receive	
55.	Record	(photography, report, display, data, diagram, table, list
56.	Reverse	(loop, response
57.	Sense	(detect, detector, discriminate, sensitivity, indicate
58.	Sequence	(series, iterate, repeat, group
59.	Solid	(cube, crystal
60.	Square	(area, surface, mean, field, plane
61.	Store	
62.	Subtract	(filter, loss, corrode, negative
63.	Tele	(distance, range
64.	Temperature	(heat, cold, hot, freeze, melt, boil, icing
65.	Theoretical	(study, analysis
66.	Time,	(clocks, interval
67.	Transmit	(tell, inform, radiate, radiation, feed, warm, emit
68.	Valve	(anode, cathode, C.R. tube
69.	Vehicle	
70.	Vision	(see, visual, optics, light, observation
71.	Wave	(wavelength, frequency, spectrum, ripple, band, waveband
72.	Liquid	
73.	Star	(solar flares, prominences, eclipse, meteors, sun
74.	Ratio	(relation)